THE GEOLOGY OF THE LITTLE ROCKY MOUNTAINS.[1]

THE Little Rocky Mountains resemble a wooded island, rising 2000 to 3000 feet above the treeless plains of central Montana, far from the Rocky Mountain Cordillera, whose nearest foothills lie 180 miles to the west. They form a conspicuous geographic feature of a region which is generally destitute of any prominences or land marks for the traveler, and hence are appropriately called by the Indians "Eah héa weetan" or the Island Mountains. They are situated north of the Missouri, between that stream and the Milk River, sixty miles south of the international boundary line. The mountains are formed by a dome-shaped uplift exposing Archæan and Palæozoic rocks, in a region of nearly horizontal Cretaceous strata. Occurring in this isolated position the uplift is of special interest, as its simplicity of structure and distance from the complicated disturbances of the Cordilleran zone make the problem a peculiarly clear one; while the occurrences of the older sedimentary strata and the relations and nature of the igneous rocks are of unusual interest, constituting a needed factor for the discussion of some of the broader problems of general geology.

As the mountains have never been mapped, the accompanying sketch showing the drainage and relief of the region, has been drawn from a few field notes, the crest line being taken from the plat of the survey of the boundary line of the Indian reservation. The altitudes of the main peaks are approximate, but the map will be found useful in locating the various points mentioned in this paper.

[1] Published by permission of the Director of the U. S. Geological Survey.

The present paper is based upon notes made during a brief visit to the region in September 1895, to report upon the mineral resources of the reservation to the Commissioners appointed to treat with the Indian tribes of the Fort Belknap reservation. W. H. Weed.

The only geological observer who has heretofore visited this region is Professor E. S. Dana, who in 1875 made a visit to the southern slopes, east of the debouchure of Rock Creek, noted the occurrences of tilted Carboniferous and Cretaceous rocks,

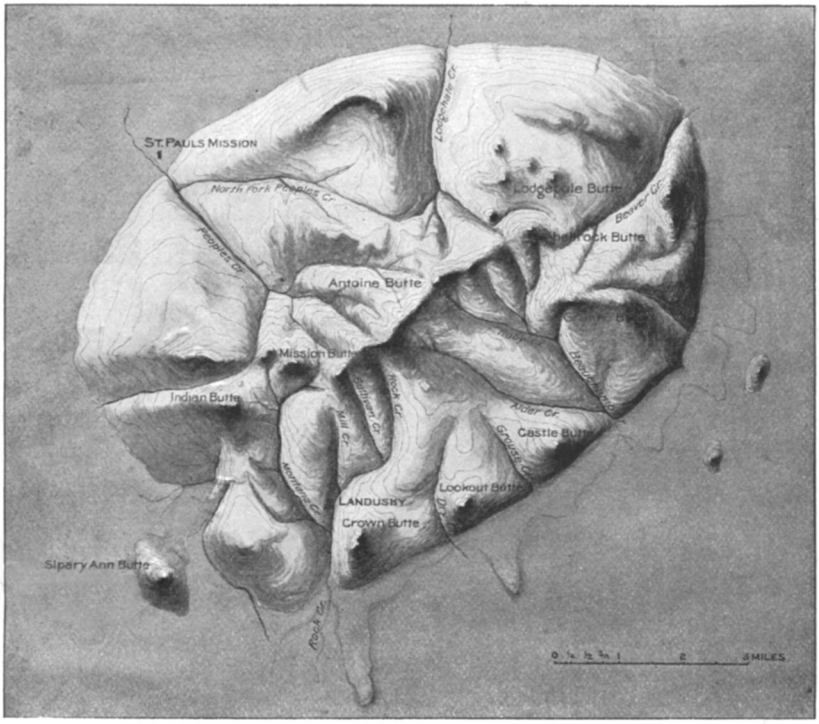

FIG. 1

and described the peculiar porphyry of the laccolithic butte at this point.[1]

In general view, the mountains rise above the plain as a broad and low, dark mountain mass, presenting an undulating crest line with no sharp peaks. A few points do stand apart from the general mass, but when seen from a distance the uplift is a single

[1] Reconnaissance from Carroll, Mont., to the Yellowstone National Park, by Col. William Ludlow, War Dept., Washington, 1876, pp. 127–130.

mountain mass rather than a chain of peaks. Several buttes rising above the slopes of the margin of the uplift form conspicuous features of the region. The highest summit reaches an elevation of over 6500 feet above the sea and about half that height above the surrounding plain. The scenery, though pleasing and attractive, is not grand, as the mountain summits are generally rounded, covered by a thick growth of small pines and are lacking in boldness and the usual striking features of Cordilleran topography. Numerous streams which head within the mountains flow in deep V-shaped gorges that trench the area, but their flowage is small and in summer water is found running only where the channel is cut in schists or porphyry. The scenery of the limestone belt, which forms the outer portion of the mountains, is quite attractive, as the heavily bedded Carboniferous limestones are cut by deep and narrow canyons and the stream valleys present a variety of vegetation that is most pleasing after traveling over the barren, grassy plains.

The only settlement within the region is the town of Landusky, which sprang into existence in the brief weeks of feverish activity consequent upon the discoveries of gold leads in the hills in 1894. The town is built in the upper valley of Rock Creek and contains some twenty or thirty houses and as many more uncompleted buildings stretching along the main street parallel to the stream; it is surrounded by rather open acclivities with scattered pines and grassy slopes, above which occasional limestone crags rise abruptly. A mail road crosses the Indian reservation from Harlem on the main transcontinental line of the Great Northern Railway, to St. Paul's Mission just northwest of the mountains, the road continuing over the mountains to Landusky.

The open plains surrounding the mountains present on the different sides strongly contrasted surface features. To the south extending to the Missouri River, is an open benchland, with long level stretches having a uniform slope of 2° toward the Missouri, and showing good exposures of the soft Cretaceous strata where cut by the streams. The surface has a scanty

covering of well-rounded stream gravel, in part of local origin and in part brought from glacial deposits. It is the type so common throughout the state south of the glacial boundary. North of the mountains the country is covered by the terminal moraine of the two continental glaciers. The surface is a rolling, broadly undulating plain with rounded, flat-topped ridges and low and wide intervening hollows. The larger drift is chiefly Laurentian and is mostly buried, except where washed out by rains or exposed on wind-blown surfaces. Bowlders over two feet in diameter are rarely seen. The quartzite drift of Rocky Mountain origin constitutes the bulk of the material and consists of smooth-surfaced, well-rounded pebbles and small bowlders of red, green, and vari-colored, well-indurated quartzites. Nearing the mountains the terminal moraine becomes more accidented, and there is a gradual ascent to a point a few miles below St. Paul's Mission, where it ends.

Cretaceous beds are seen exposed near the foothills, and steep, grassy, slopes rise up to the white wall of limestone that everywhere encircles the mountains. This limestone wall is perhaps the most prominent feature of the mountain mass when it is seen from a distance, the huge white scollops into which the sharply upturned beds have been cut by erosion being visible for fifty miles from the surrounding plains. Above this limestone wall dark wooded slopes rise abruptly to the rounded summits of the mountains.

Geological structure.—The mountains are formed by a single dome-shaped uplift having a nucleal core of crystalline schists, and involving Palæozoic limestones and the softer overlying Mesozoic beds. This structure has been slightly modified by the intrusion of a great laccolithic body of granite porphyry. The uplift fades out in the minor puckerings of soft Cretaceous beds about the mountain flanks. The strata underlying the surrounding plains are essentially horizontal. This geological structure is shown in the accompanying diagrammatic cross-section of the uplift, Fig. 3, p. 412, which shows the relatively low, broad character of the folding and the relation of the granite

porphyry intrusion to the nucleus of crystalline schists and the overarching sedimentary beds. It is a miniature representation of the geological structure of the Black Hills of Dakota.

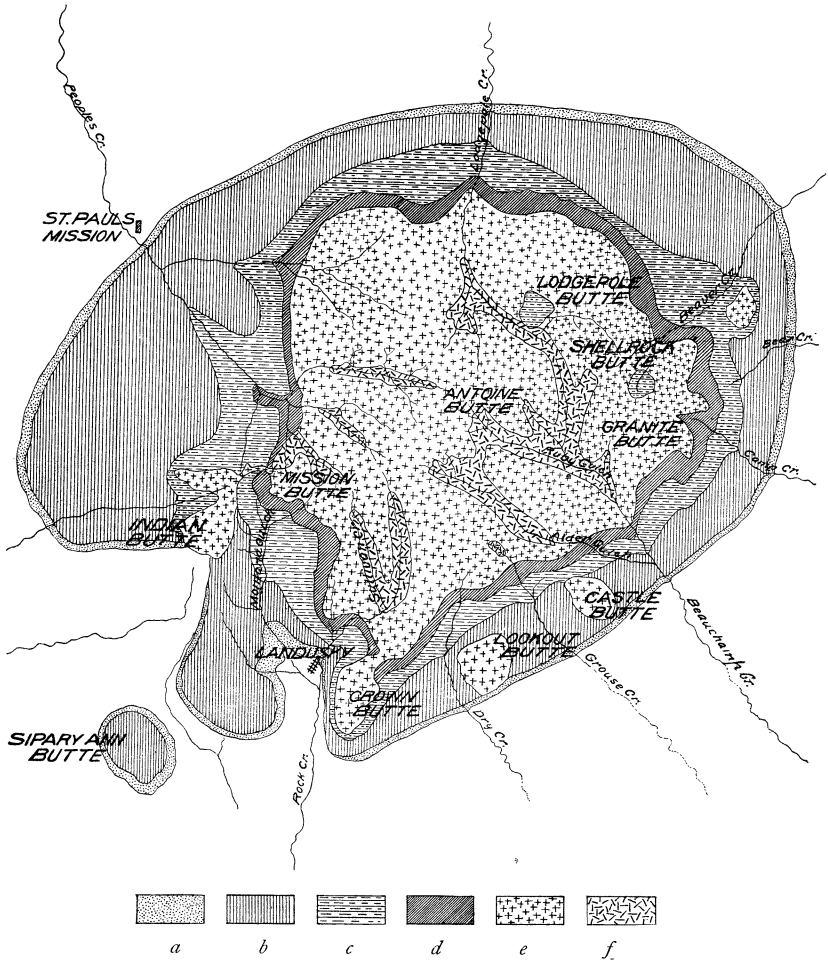

FIG. 2.—*a* = Jurassic; *b* = Carboniferous; *c* = Siluro Devonian; *d* = Cambrian; *e* = Porphyry; *f* = Crystalline Schists.

In the brief time spent in the region no attempt was made to trace out geological boundaries nor to measure detailed sections, it being necessary to ascertain the character and age of

the rocks and the structure of the uplift. The accompanying geological map (Fig. 2) therefore represents merely a sketch of the surface distribution of the various rocks and their general relations to one another, boundaries being drawn without any pretensions to detailed accuracy. The great areal extent of the porphyry is at once seen on the map, and the fact that where the streams have trenched through it the underlying crystalline schists are exposed.

Archæan-Algonkian.—The nucleal core of the mountains is formed of crystalline schists. These rocks are exposed in the headwater gorges of all the larger streams and in the deeply cut saddles of the main crest or ridge of the mountains. The type most usually seen is a black, glistening amphibole schist, or amphibolite, fine-grained, dense, and compact, splitting into flat, bright-surfaced fragments. In the saddle west of Shellrock Mountain the rocks of the series are schistose, occurring in beds but a few feet thick and of rapidly alternating character, showing garnetiferous amphibole and mica schists, pink gneiss with sheared and elongated feldspear crystals, and white quartzites that are clearly altered sandstones. The presence of this latter rock makes it certain that the series is of sedimentary origin, as the original grains are well rounded though now firmly cemented. This would place the rocks in the Algonkian series, but similar schists occurring in Montana have been generally classed as Archæan, and these beds are metamorphosed and quite unlike the slightly altered Belt Mountain Algonkian series.

SEDIMENTARY ROCKS.

The sedimentary rocks form the dominant feature of the region as seen from the surrounding plains. The geological section embraces rocks of the Cambrian epoch, together with a considerable thickness of rocks whose age is not definitely known, occurring beneath limestones carrying characteristic lower Carboniferous fossils. The Mesozoic is represented by Jurassic limestones, and a thickness of several thousand feet of Cretaceous beds, which are found, however, only in the hills

and plains country about the mountains. The following, Table I, shows the general sequence of the sedimentary series. No Lower Cambrian, Upper Carboniferous, or Triassic rocks occur in the region. The oldest unaltered stratified rocks are of Middle Cambrian age. The base of the sedimentary series is a fine, dense quartzite of a pale pink or flesh color, which is sometimes a conglomerate at the base, the pebbles being of clear or slightly turbid quartz. *Scolithus* borings were observed in this bed, but no fossils were found. Overlying this the lowest and oldest of the unaltered sedimentary rocks is a series of shales of greenish or reddish colors, of which no good exposures were found.

TABLE I.

Cretaceous,	Sandstones and shales.
Jurassic,	Limestones.
Carboniferous,	Limestones; massive, very heavily bedded, white rocks. Limestones, laminated, ochreous stained, forming reddish exposures.
Devonian?	Limestones; thinly bedded, gray.
Silurian?	Limestones; dark gray and black, fetid, mottled beds.
Cambrian,	Alternating micaceous shales, impure sandstones, glauconitic limestone, and limestone conglomerate. Shales. Quartzite.
Algonkian or Archæan,	Crystalline schists, gneiss and quartzite.

Fine sections of the limestones are to be seen in almost all of the canyons cut by the mountain streams. The canyon of Peoples Creek, along the channel of which the road from St. Paul's Mission to Landusky has been built, shows especially good exposures of these rocks. The beds dip at 10° down stream and are cut in a narrow gorge. The Cambrian rocks are not well exposed, but have been eroded into a little park or valley between the higher porphyry slopes and the limestone plateau.

Near Landusky the Palæozoic limestones, though prominent features of the landscape, do not present good sections, but the

Cambrian shales are well exposed above the town, and the dark gray, shaly, Jurassic limestones form the foot slopes near the settlement.

Cambrian.—A half mile above Landusky the west bank of Mill Creek shows exposures of 75 to 100 feet of quartzite resting upon the main porphyry mass, which has been intruded between the Cambrian quartzite and the Archæan nucleus of the hills. Above the quartzite are greenish gray shales of which no good exposures were seen, probably 200 feet thick and succeeded by sage-green shales carrying poorly consolidated conglomerates and lenses of glauconitic limestone two inches thick and of varying size. The shale is evidently somewhat calcareous and micaceous, and shows fucoid rolls. The exposure is but 150 feet long, and the shaly series is overlain by thinly bedded limestones. The following section was made at the locality:

No.	Feet	
6	25	Thinly bedded and fissile limestones. Pure limestones with shell remains, alternating with impure, sandy, and more or less conglomeratic beds, the general color being gray.
5	40	Limestone conglomerates and gray shales; greenish sandy layers alternating with purer argillaceous beds. A few thin beds of limestone occur from which a few fossils were taken.
4	50	Green shale beds, carrying limestones and conglomerates.
3	30	Green or copperas-colored shales.
2	300?	Interval in which the beds are not exposed.
1	75	Quartzite, changing to conglomerate near the base; generally flesh colored; mostly brecciated and rusty.

These rocks dip at an angle of 40° toward the town, the strike being N. 60° W. The conglomerates of this section are clearly formed of beach shingle, as the pebbles are all flat. The rocks are very loosely cemented and easily disintegrable, which accounts for the rarity of exposures of these beds throughout the mountains. The impure sandstones interbedded with the shales consist of rounded quartz grains with a green coating or shell of glauconite.

The fossils from the limestones forming part of No. 5 of this

section have been examined by Professor C. D. Walcott, who has identified the following species:

Ptychoparia Owenii Hall.

Obolella nana Meek and Hayden.

Both are Middle Cambrian forms.

Siluro-Devonian rocks.—Above the Cambrian series there are dark-colored, slate-gray and black, fetid limestones possessing the general characteristics of the Silurian and Devonian series as developed in the Rocky Mountain region to the westward. These rocks, however, have not yet been found to contain fossils, and the assumption of their Silurian age is based upon their lithological character and their position between the Cambrian rocks and those of Carboniferous age. The Devonian was not recognized, but in its occurrence westward in the Rocky Mountain province, it is recognizable with difficulty, and the lithological charaçter of the rocks found here indicates that careful search may reveal characteristic fossils of this age.

Carboniferous.—The Carboniferous rocks are well developed and form a series of somewhat thinly bedded limestones at the base, several hundred feet in thickness, which are capped by massive, heavy bedded, structureless limestones which appear to be characteristic of the upper part of the Carboniferous throughout the northern Rocky Mountain region. These are the limestones whose upturned beds form the encircling girdle of the mountains, and in which the picturesque canyons of the streams are cut. Characteristic Carboniferous fossils were observed at a number of exposures. Professor E. S. Dana collected a few fossils from these beds in the canyon east of Rock Creek, identified by Professor Whitfield[1] as follows:

Glauconome sp.?

Productus sp.

Chonetes sp., resembles C.; *granulifera* Owen, also C.; *subumbona* M. and W.

Chonetes sp.

[1] Reconnaissance from Carroll, Mont., to Yellowstone National Park, by COL. WM. LUDLOW, Washington, 1876, p. 129.

Spirifer centronata Winch. "The general expression of these fossils is Lower Carboniferous."

Jurassic.—Overlying the massive, structureless limestones which form the top of the Carboniferous series and are really the most prominent sedimentary rocks of the region, are thinly bedded rocks which generally form somewhat gentle slopes at the base of the steep limestone cliffs, or bedding slopes. These rocks form somewhat detached hillocks of the hogback style, the hillocks being fifty feet high and separated from the limestone slopes by a gentle sag or depression. These beds consist of shaly, gray limestones, carrying Jurassic fossils and changing gradually into impure, marly shales and argillaceous limestones, carrying a fauna of marked Jurassic types. The total thickness is about 100 feet. Good exposures of these beds are found near the town of Landusky, where the road descends from the heights along the slope of Indian Butte. The following fossils collected from these beds have been examined by Mr. T. W. Stanton, who reports the presence of the following species:

Ammonites; fragments of an undecided species.

Belemnites densus M. and H.

Pleuromya subcompressa Meek.

Astarte Meeki Stanton (ms).

Modiola subimbricata Meek.

Gryphæa calceola, var. *nebrascensis* M. and H.

"This is evidently from the Jurassic horizon that is so well represented in the Yellowstone Park and adjacent parts of Montana."

Cretaceous.—The Jurassic rocks are capped by a bed of buff-colored, massive sandstone which weathers red and is six feet in thickness, the rock merging into a variety that breaks down so readily, forming a sandy soil, that no outcrops are seen; its thickness is about twenty feet. This sandstone is capped in turn by a thickness of gray, arenaceous shales. These last beds are in turn capped by sandy shales for at least 300 feet, above which there is a sandstone bed of five to ten feet in thickness, which when exposed forms a long wooded ridge separating the depressions eroded in the soft shales. This sandstone lies at

the base of a series of leaden blue shales, which vary in their character and do not appear to be the "gumbo" shale characteristic of the Pierre beds, so common in the plains country south of the mountain. These shales carry a few fossils and are overlain by other shales carrying sandstone concretions, from which numerous fossils were obtained and which were kindly identified by Mr. Stanton.

Goniobasis sublævis M. and H.

Corbicula cytheriformis M. and H.

Ostrea sp.

This shale series is in turn capped by white, porcellanous beds, in which there are abundant impressions of fish scales. This rock weathers into a sherdy, porcelain-like débris, whose light color attracts attention whenever the rocks are exposed.

IGNEOUS ROCKS.

Distribution.—Igneous rocks cover a considerable part of the Little Rocky Mountain region, forming the central area and occurring in several marginal buttes, the distribution being shown on the accompanying geological map (Fig. 2, p. 403). The rocks are porphyries, belonging to the granite-syenite series, and are of highly alkaline types passing into the phonolites, one rock belonging to the latter family occurring near Landusky.

Occurrence.—The porphyry occurring in the central area of the mountains belongs to a single large body, intruded conformably in the arch of the uplift between the crystalline schists and the Cambrian limestones, the soft shales of the latter formation affording an easy horizon of fracture and intrusion. This is shown in the diagrammatic cross section of the mountains (Fig. 2, p. 403) in which the porphyry is represented as a single intrusive mass, thickened on the summit of the low flat arch and thinner at the edges. This seems to be the actual occurrence in the mountains, though the precise thickness between the limestones and crystalline schists was not measured. This makes the intrusion laccolithic in character.

The cross section shows a thinning of the laccolith to the

east, as actually observed north of Shellrock Butte, with a thickening of the mass beyond. While the observed facts seem to indicate a fairly uniform contact plane between the schists and the base of the porphyry, the upper surface is not so regular, as is shown by the occasional occurrence of areas of limestones as blocks of warped strata at elevations considerably below the highest porphyry peaks. The porphyry intrusions of the marginal summits, such as Crown Butte, Indian Butte, and similar elevations, appear to be small laccolithic bodies of the porphyry breaking through the massive limestones, as is the case at Indian Butte, where the igneous rock occurs in contact with the black shale of the Cretaceous.

If the soft nature of the shales was the determining factor for the intrusion of the porphyry at this horizon, then the parting of the beds by the intrusion would be between quartzite and shale; this is, however, not always the case, for the quartzite at the base of the Palæozoic series is sometimes found beneath the porphyry, between this rock and the crystalline schists, and sometimes above it, and beneath the soft Cambrian shales.

No dikes or ordinary intrusive sheets were observed in the mountains, nor are there any extrusive rocks either here or in the immediate vicinity.

The gulches which cut the porphyry areas are very deep, with steep slopes heavily timbered with pole pine from three to twenty feet high, and the creek bottoms can only be traversed with difficulty. The porphyry is some three or four hundred feet thick upon the principal summits and rests upon black mica schists, into which the streams have cut their gorges, the walls on either side showing typical Archæan exposures capped by great débris slopes of porphyry. The character of the rock formation is readily indicated by the vegetation, as the porphyry exposures and débris slopes are everywhere covered by young pines or, more rarely, form smooth grassy slopes, while the limestone and schist areas are covered by the big-leafed pine, which forms open groves and show occasional rough outcrops of the country rock.

The ridge extending southward from the main divide to the

Alabama mine shows a porphyry, varying slightly from that of the main ridge. Its most noticeable character, however, consists in the prominent white crystals with which it is dotted. The rock shows smooth, slickensided surfaces, and in general crushing and rock movement.

The contact between the porphyry and the Archæan schists was observed on the high ridge east of Antoine Butte. Here there is an exposure of schists some 200 yards across, which shows on the crest of the ridge. The porphyry immediately overlying the schists is somewhat decomposed, and the contact is marked by five feet or so of green clays. The contact has a dip to the south of about 30°.

Parting.—The parting varies in different parts of the mass. At the west base of Mission Butte the porphyry has a platy parting or lamination near the contact with the limestones, and the rock is dense and resists weathering so well that the contact is marked by a wall rising above the adjacent slope of shale and porphyry. At Mission and Granite buttes the rock is a granite porphyry, breaking into massive blocks—the normal jointing of a granular rock. Throughout the mountains generally, however, the porphyry upon weathering breaks into rather small angular fragments, usually but a few inches across, and forms broad slopes of débris covering the mountain sides.

Vent.—The rock body is in the diagram shown extending downward at the side of the arch, but it seems evident that the injection did not take place through the entire circumference of the ring. It becomes, therefore, a matter of interest to locate, if possible, the vent by which the rocks reached the horizon in which they were intruded. The uniform granularity of the rocks observed shows that there is no large stock or core which may be supposed to represent the source of supply. In fact all the indications show that the intrusion is analogous in form to a laccolithic sheet.

South of Mission Butte the slopes back of the Goldbug mine show outcrops of breccias formed of fragments of porphyry with large blocks of quartzite, the latter rock resembling that forming

the basal bed of the Cambrian series. This breccia occurs in rough, craggy masses on the slope immediately above the mine. The crest of the ridge above the mine is formed of a breccia composed of pieces of porphyry in which no quartzite was noticed. At this locality the crest of a lateral ridge north of the mineralized belt is formed of a fairly dense porphyry, which is somewhat brecciated, is mineralized, and generally of a light

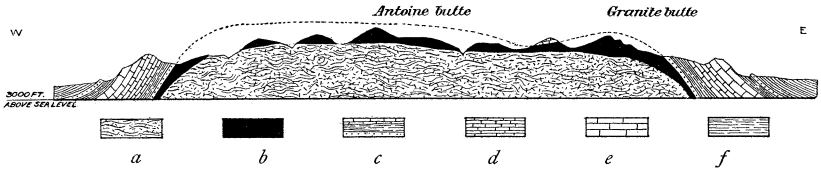

FIG. 3.—*a* = Crystalline Schists; *b* = Granite Porphyry; *c* = Cambrian; *d* = Siluro-Devonian; *e* = Carboniferous; *f* = Mesozoic.

purple or reddish color, the rock carrying about $2.50 in free gold per ton. West of the Goldbug mine the same brecciated porphyry occurs, with the quartzite above it dipping west, and the Cambrian limestones, conglomerates, and shales which occur at this place are somewhat baked and indurated. It is believed that the breccias near this Goldbug property mark the point of eruption of the porphyry magma. This is strengthened by the baking of the sedimentary rocks in contact with this breccia on the west.

Contact metamorphism.—Throughout the Little Rocky Mountains there is but little contact phenomena to be noticed in the sedimentary rocks about the porphyry intrusions. The only place where this action was noticeable is in the vicinity of the Goldbug mine, where the induration and consequent different fracture and weathering of the sedimentary rocks adjacent to the porphyry mass is quite marked, although it is here but a few yards in extent. Elsewhere throughout the mountains no contact metamorphism of any consequence was observed, not even where the intrusive rocks have come in contact with the Cretaceous shales or the massive Carboniferous limestones, as they do in Crown Butte and in the eminence west of Mission Butte.

Petrography.—The main mass of the mountains, including the

central peak, Antoine Butte, is composed of *granite-porphyry*, normally of a gray color and distinguished by large phenocrysts of orthoclase. The rock usually falls apart on weathering into rather small angular blocks, rarely plates which are sometimes a foot in diameter but more often much less, the débris forming extensive slides and talus slopes. A specimen from the main crest near Antoine Butte, typical of the vicinity, is a *granite-syenite-porphyry*. Seen in the hand specimen the rock is compact and dense, of pale lavender-gray color, and shows abundant equidimensional phenocrysts of opaque white feldspar of 1 to 3^{mm} across, thickly scattered throughout the rock. Large crystals of pale flesh-colored glassy orthoclase from 10 to 15^{mm} in length are less abundant, but form the most prominent constituent. The rock is strippled with blackish specks that are probably a decomposed ferro-magnesian mineral. The rock weathers with rusty or reddish-brown stained surface, on which the large orthoclase phenocrysts are very conspicuous.

The section discloses under the microscope an abundance of large phenocrysts of feldspar lying in an extremely fine-grained groundmass composed of quartz and feldspar. Some iron ore is present, dotting the section in very fine, numerous grains. No ferro-magnesian mineral is seen, but very rare small pseudomorphs of muscovite mixed with iron ore show that formerly an extremely small amount of biotite in little tablets was present.

The feldspar phenocrysts are composed of orthoclase and oligoclase. The orthoclase is present in large crystals of the usual type showing the faces $m(110)$, $b(010)$, and $c(001)$, and in habit is stout columnar along the a axis. It is twinned at times according to the Carlsbad law and is then thick tabular on $b(010)$. A section perpendicular to the obtuse bisectrix gave an extinction angle of about 8° from the cleavage parallel to $c(001)$. The crystals of orthoclase are often grouped.

The plagioclase is present in stout tabular crystals, which are usually not so large as those of the orthoclase. There is also less of it in amount. That it is oligoclase is shown by the fact that numerous sections oriented in the zone perpendicular to

b(010) according to Michel Levy's method, and which show both albite and Carlsbad twinning extinguish nearly parallel to the plane of the nicols, the angles for all lamellæ varying but a degree or two. The difference in illumination in the Carlsbad halves for such sections is consequently very small. The total amount of phenocrysts in proportion to groundmass is large.

The groundmass is exceedingly fine-grained, microcrystalline, almost cryptocrystalline in fact; the great difference between the large phenocrysts and the fineness of the groundmass being one of the striking features of the rock. Examined with high powers it is seen to be composed of unstriated feldspar with a subordinate amount of quartz. The feldspar is turbid, apparently from leaves of kaolin. The fineness of grain together with the turbid character, and lack of contact lines between fresh feldspar and quartz prevents the satisfactory determination of the feldspar by Becke's method or other optical means. We can safely conclude, however, from the analysis that plagioclase is not present and that it must consist mainly of orthoclase with some addition of the albite molecule, since the very small amount of lime must be entirely used up in the production of the oligoclase phenocrysts. An analysis by Dr. H. N. Stokes of the United States Geological Survey furnished the following results:

SiO_2	68.65
Al_2O_3	18.31
Fe_2O_3	.56
FeO	.08
MgO	.12
CaO	1.00
Na_2O	4.86
K_2O	4.74
Li_2O	trace
TiO_2	.20
MnO	trace
BaO	.13
SrO	.10
H_2O above 110°	.83
H_2O below 110°	.27
Fl	trace
Cl	.03
SO_2	trace
P_2O_5	trace
Total	99.88

The striking feature of this analysis is the exceedingly small

percentage of lime, iron, and magnesia. In spite of the presence of the oligoclase the rock clearly belongs in the alkali series; had more iron and magnesia been present we should expect the lime would have been partly exhausted by the production of augite or hornblende; their absence has forced it into the feldspar. Their absence also explains why with such a comparatively high silica per cent. so little quartz is present; it has nearly all gone into the production of feldspar, of which the orthoclase molecule demands 64.7 per cent., the albite 68.7, while only a very small proportion of the anorthite molecule with SiO_2=43.2 is present.

If we neglect the minute amount of potash present in the muscovite and consider all the alkalies and lime as present in the form of feldspar molecules, their molecular proportions

K_2O	503
Na_2O	783
CaO	179

show that they are in round numbers present as follows: Or_{10}, Ab_{15}, and An_2. Since the optical properties of the oligoclase present show it to have approximately the composition Ab_4 An_1 and since albite has not been observed, it is clear that anorthoclase must be present to a considerable extent, in the groundmass.

The lateral ridge at the head of Alder Creek, southeast of Sullivan Butte, is formed of a rock that is slightly different from that of the main ridge, and which being free from quartz, is classed as a *syenite porphyry*. This is cut by zones or leads of decomposed rock, several of which have been prospected. Near the Hawkeye mine where the rock has undergone secular disintegration, the feldspar phenocrysts have occasionally weathered out and form a coarse, sandy débris covering the rock outcrops on the summit of the ridge. The rock is compact, dark, pinkish gray in color, with abundant white phenocrysts of orthoclase which are from 10^{mm} to 20^{mm} across, small phenocrysts of an opaque white feldspar, and small cavities due to the decomposition of some ferro-magnesian mineral are common.

Under the microscope the rock is seen to consist of large

feldspar phenocrysts in a feldspathic finely granular groundmass. Only occasional ferruginous products represent some former ferro-magnesian mineral. The large feldspar phenocrysts are chiefly orthoclase, but there is also a plagioclase present whose optical properties indicate an acid oligoclase. The groundmass in which these lie is composed of unstriated alkali feldspar with quartz practically absent. It is micro-granitoid in structure, with tendency to a broad trachytoid type like those seen in the orthophyres. The rock is considerably altered, the groundmass quite turbid from kaolinization, and the feldspars are also changed though interior cores are still fresh and limpid.

Mission Butte is the sharp, somewhat isolated mountain that is the most prominent point of the western part of the mountains. It is composed of *granite-porphyry* weathering in crags that form a sharp summit that is in strong contrast to the smooth and purple débris slopes and pine covered flanks of the adjacent mountains. The character of this porphyry is somewhat unlike the type prevailing in the mountains. It weathers in rough crags, and breaks in irregular surfaced blocks, in sharp distinction to the fine débris which generally prevails throughout the range. At the west base of the butte where the porphyry is in contact with the sedimentary series, the contact form of the rock resists weathering more effectively than the main body of the porphyry, and forms a wall projecting above the general surface of the ground. In this outcrop the rock is platy, and the lamination is parallel to the contact and to the bedding of the limestone.

The rock, although it differs in weathering and in the appearance of its craggy outcrops from that forming the main mass of the mountains, upon microscopical examination is found to be a facies of the same rock. It is a granite-porphyry with somewhat open structure and miarolitic cavities; has a generally light rusty-gray color, and contains large phenocrysts of glassy orthoclase 10^{mm} to 15^{mm} in diameter, with abundant and less prominent square feldspar crystals of somewhat uniform size, which are 2^{mm} or 3^{mm} across; occasional corroded quartz grains are also

present. The rock is somewhat decomposed, and the cavities are filled with rusty material which produces the yellowish tint of the rock.

The micro-section shows large crystals of feldspar as phenocrysts in a fine-grained groundmass of feldspar, with some quartz. The rock is dotted with fine particles of iron ore and probably a very little biotite was formerly present. The description given of the rock from the main crest, p. 413, will apply perfectly to this rock except that the orthoclase phenocrysts are at times quite large, and on the whole there is less quartz in the fine, microcrystalline, granular groundmass. The feldspar phenocrysts are very fresh, clear, and unaltered, the groundmass rather turbid.

On the north slopes of Mission Butte the underlying schists are exposed beneath the porphyry, the rocks being dark and micaceous. The hilly country lying between Mission Butte and the limestone ridge which forms the northern limit of the mountain mass is devoid of large timber, and the surface appears to be covered entirely by porphyry. A specimen obtained on Peoples Creek, a short distance above the saw-mill, shows a fine-grained rock, breaking readily into large débris blocks which cover the mountain slopes. The rock is of a buff color, but the dark-colored outcrop is so covered by lichens as to closely resemble the quartzites of the Cambrian and deceive the observer. The rock is found just above the Indian's saw-mill, where it occurs near the contact with the sedimentary rocks. It represents a variety not noticed elsewhere in the mountains. It is a compact, dense rock of a decided pinkish buff color, with abundant small phenocrysts of feldspar which are sometimes tabular, and with occasional grains of quartz 1^{mm} across. The rock shows small cavities due to the decomposition of some ferro-magnesian mineral, which on the weathered surface form small pits that are quite conspicuous.

This type is quite similar to that forming Antoine Butte and the central mass of the mountains, except that the phenocrysts are smaller and more thickly crowded. There is also less oligoclase and nearly all of the phenocrysts are of the type of the

orthoclase in the preceding rock. Anorthoclase is probably largely present. The feldspars have been slightly kaolinized—the groundmass, which is similar in character to 920, much more so. No ferro-magnesian mineral was observed save an occasional tiny fiber or shred of ægirine and almost no iron ore; the rock consists almost entirely of alkali feldspars and is practically a sanidinite-porphyry. It belongs clearly in the alkali series.

Shellrock Butte is a round-topped eminence, separated by a deep saddle from Granite Mountain to the east and an equally low divide from the main mountains to the west. The lower slopes are formed of metamorphic schists which show considerable variety, including sheared granite, garnet schists, feldspar schists, and black mica and hornblende schists. The saddle west of this mountain is formed by the head waters of a branch of Lodgepole Creek and of Ruby Creek. The schists extend upward some two or three hundred feet above the saddle. Above this point they are covered by the porphyry débris, which hides the contact and obscures the exact relationship of the two rocks.

Granite Butte is the name applied to the most striking summit and highest elevation of the eastern end of the range. Gentle northerly slopes are in abrupt contrast with a bold craggy summit, abrupt cliffs, and steep rock débris slopes on the south. It is probably the highest point of the mountains, and consists of a granite-porphyry which is somewhat different in appearance from the rock prevailing generally throughout the range. The rock is open in structure and weathers in great blocks that lie piled one upon another like rude masonry.

The rock is a *granite-diorite-porphyry*. It is a somewhat compact rock of a light-gray color, characterized by large crystals of glassy orthoclase which are sometimes 20^{mm} across, and small phenocrysts of opaque white feldspar. Round grains of glassy gray quartz are abundant, and vary in size up to 5^{mm}. The rock also carries stout prisms of chloritized augite, which on the weathered surface have left cavities giving the rock a pitted appearance that is quite noticeable.

In thin section it is seen to be very much the same rock as that forming the central part of the mountains. Large feldspar phenocrysts with fewer ones of quartz in a very fine, quartzose, feldspar groundmass. Only an occasional patch of opacite gives clue to a former ferro-magnesian mineral now resorbed, perhaps biotite.

The large feldspar phenocrysts are mostly of oligoclase or oligoclase-albite, as determined by the method of Michel Levy; they show both albite and Carlsbad twins and are present in thick tabular habits. Orthoclase, though not so prominent, is also largely present. A little sphene was noted. These minerals lie in a fine granular groundmass of micro-granitoid structure, composed of non-striated alkali feldspar and quartz. A few occasional granules of albite were noted in it.

Phonolite.—A rock presenting a marked difference in character from those so far described was obtained from the borders of the porphyry mass, north of Landusky. The rock is the variety of phonolite called *tinguaite* and is found beneath the basal quartzite of the Cambrian, between it and the main mass of porphyry seen on Mill Creek above the town. The rock is a dense, dark-green porphyry, and at the time it was collected was supposed to be a contact form of the main porphyry mass. The same rock was found near the contact between the intruded porphyry mass of Indian Butte and the overlying limestones. A similar rock was found near the Spotted Horse mine in the Judith Mountains, where it also occurred at the contact between the porphyry mass and the altered sedimentary rocks. While definite observations were not made to ascertain if this rock occurs as a dike, yet the fact that it is found in these different localities, and in each case is supposed to be a contact form, seems to negative the idea that it is a dike rock. If, however, this rock does occur as a contact form of the main porphyry mass it is a most interesting occurrence and tends to show a marked differentiation of the main mass toward the cooler periphery. The rock is quite fissile, splitting readily into irregularly surfaced plates, this being due to a parallel arrangement of the tabular feldspar crystals.

It is an aphanitic, very tough, dense and compact rock of a very dark greenish stone color, having a resinous appearance on fresh fracture. Numerous white feldsar phenocrysts, which attain a maximum size of 10^{mm}, occur scattered through the dark groundmass, with rarer small crystals of ægirine-augite in stout black prisms. Prismatic crystals 3 to 4^{mm} in length of a light-brown translucent mineral occur in the rock, but their nature has not been determined for lack of sufficient material.

Occasional small patches of a brown, metallic-lustered mineral are also present, which is shown by its color, by its magnetic properties, and a reaction for sulphur, to be pyrrhotite. The occurrence of this mineral in an extremely fresh and unaltered igneous rock is quite in accord with the rapidly accumulating evidence which different observers are furnishing in regard to the occurrence of metallic sulphides in basic rocks.

In thin section the rock shows large phenocrysts of alkali feldspar and smaller ones of augite in a fine groundmass, of alkali feldspars, ægirite, and nephelite. The large phenocrysts of feldspar are fresh and of sanidine-like character. They are developed very thin tabular on *b* (010) and are usually twinned according to the Carlsbad law. An endeavor to obtain definite data concerning the optical properties of these feldspars was not successful. The augites are stout columnar crystals of ægirine-augite with mantles of ægirine. They do not show any noticeable dispersion of the optic axes. Rarely some rather large crystals of zircon occur.

The groundmass in which these phenocrysts lie is composed of irregular, lath-like, unstriated feldspars arranged in a pronounced trachytoid structure which shows at times a fluidal arrangement. Sometimes the feldspars are in short rectangular forms. They show the patchy, flamed appearance so characteristic of anorthoclase, where the composition varies from place to place between the molecules Ab and Or. No albite twinning is, however, present, but the majority are singly twinned according to the Carlsbad law. Scattered freely through this trachytic groundmass are great quantities of rather short, stout microlites

of ægirite, while between the irregular lath-like feldspars occasional nephelite is seen as a cementing product. The rock powder treated with acid is found to gelatinize readily, thus confirming the presence of the nephelite; the solution in HNO_3 reacts with silver nitrate for chlorine, but gives no reaction with barium chlorides for sulphates, and it is probable that a small amount of sodalite is present but no hauyn or nosean.

The rock is very fresh, an occasional slight kaolinization of the feldspar being the only alteration product seen. From the association with ægirine and nephelite and from the absence of any plagioclase, it is clear that the rock is composed chiefly of anorthoclase with accessory ægirite and nephelite. It thus stands closely related to the Sölvsbergite of Brögger[1] and is an intermediate type between that rock and the nephelite rich tinguaites.

The buttes rising above the mountain slopes near the borders of the uplift are laccolithic bodies of porphyry, whose rocks present slight differences of character from those of the main intrusive mass. The limestone hills at the extreme eastern end of the range and Siprary Anne Butte near Landusky may represent similar laccolithic bodies, in which erosion has not as yet uncovered the eruptive rock.

Crown Butte is the crag-topped mountain which rises abruptly some 600 feet above the town of Landusky. It is composed at the base of massive Carboniferous limestone, which forms an incurved mass between this butte and that near the Goldbug mine.

The laccolithic mass of porphyry forming *Crown Butte* consists of a granite porphyry almost identical with that forming the main mass of the mountains. Seen in the specimen it is a somewhat altered porphyry, showing considerable staining due to oxidation. The rock is generally of a bluish pink color, showing a stony groundmass of a pronounced lavender tint through which are scattered numerous flesh-colored phenocrysts of orthoclase, with minute crystals of altered micaceous material and occasional glassy grains of quartz.

[1] Grorudit-Tinguait Serie, p. 67, Christiania, 1894.

The rock is seen in thin section to be almost exactly like that of the main crest, except that it contains occasional phenocrysts of quartz and the groundmass is of finer grain. It is a typical granite-porphyry with numerous phenocrysts of orthoclase and oligoclase, with occasional partly corroded, resorbed quartzes all of rather large size in an alkali feldspar, quartzose groundmass. This groundmass is excessively fine in grain, almost cryptocrystalline, and the contrast between the size of the phenocrysts and the fineness of the groundmass is even more striking than in that of the main crest.

Indian Butte, west of Landusky, across whose slopes the wagon road has been built, is an extensive body of *syenite-porphyry* breaking through the sedimentary rocks somewhat irregularly. The porphyry is a compact, rather dense rock of a pinkish gray tint, showing numerous small phenocrysts of white feldspar and occasional large crystals of glassy sanidine which are some 10 to 12^{mm} across. The rock is stippled with abundant small black crystals of hornblende, which vary greatly in size and give the rock a general appearance quite different from that prevailing throughout the mountains. No quartz is noticed in the hand specimen.

The thin section under the microscope shows large phenocrysts of orthoclase and smaller ones of oligoclase, with well crystallized prisms of green hornblende imbedded in an extremely fine-granular groundmass of alkali, unstriated feldspar. Apatite, titanite, and iron ore are also present. The oligoclase is often zonally built with layers ranging from acid andesine to oligoclase, this being shown in the optical characters where Carlsbad twins occur. The groundmass is peppered through with excessively minute shreds of a brownish mineral of strong double refraction, which is held to be biotite. The proportion of phenocrysts to groundmass is rather large. The hornblende increases in the depth of its green coloring toward the periphery.

Lookout Butte lies a few miles from Landusky, its porphyry slopes interrupting the white encircling wall of limestone that terminates the mountain slopes on the south. This butte was

ascended by Professor Dana in 1875, who noted its character and height and briefly described[1] the porphyry, the specimens obtained by him being identical with those obtained last summer, as shown by comparison of the hand specimens.

The rock is a syenite-porphyry of very pale-brown, nearly white color. In a groundmass which can be seen by the eye to be very finely granular, there are numerous phenocrysts of orthoclase from one-quarter to one-half inch long, bounded by the usual faces *m* (110), *b* (010), *c* (001), and often *y* (201); they are equidimensional in habit. No ferro-magnesian minerals are seen, but on weathered surfaces the rock has a rusty color due to the oxidation of a small amount of iron ore.

In thin section the rock appears wholly made up of feldspars with a little interstitial quartz. An occasional opacite-like patch shows the existence of a former sparsely scattered iron-bearing mineral which from the shape of the patches and a consideration of the character of the rock seems most likely to have been ægirite. The large feldspar phenocrysts are unstriated; they are quite fresh, sharply bounded, and present several points of interest mentioned beyond. From a consideration of the large amount of albite in the rock it is probable that they are soda-rich orthoclases.

The groundmass of the rock in which the phenocrysts mentioned above are imbedded consists of equidimensional grains of albite, which give short rectangular cuts in the section. The average size of these grains is about one to one-half millimeter in diameter. They show the albite twinning extensively developed and usually in very fine lamellæ; the lamellæ often are interrupted and die out in wedge-shaped strips and then commence again; they appear remarkably like the albites which occur in the Litchfield eleolite-syenite from Maine, and which have been described by Bayley,[2] only that they are not bent or broken. Very rarely the pericline twinning is seen and some-

[1] Op. cit. This is the same rock collected and described by Dana, 1875 (Ludlow report), pp. 128, near top, 129 bottom, and 130 top.

[2] Bull. Geol. Soc. Am., Vol. III, pp. 231 to 252, 1892.

times the Carlsbad. The determination of this feldspar as albite is based upon the facts that in sections in the zone perpendicular to *b* (010) chosen according to Michel Lévy's method, the maximum extinction angle is 16°. One such section gave for one albite twin 16°, for the other 15°, the Carlsbad half, distinguished by the shape of the section, the arrangement of the lamellæ and a very slight but perceptible difference in double refraction in the position of equal illumination, gave extinction angles so nearly similar that the two are practically alike. In convergent light the section shows the exit of a negative bisectrix, but owing to the fineness of the lamellæ the hyperbolas are broken and the image does not permit one to say whether the bisectrix is centered or not. The presence of the quartz and the clearness of its contacts with the albite permit of the use of Becke's method. Both in the parallel and crossed positions the quartz is always found to be the more strongly doubly refracting. All of these determinations point clearly to albite and a quantitative determination of CaO in the rock showed a mere trace of it to be present. The spaces between the albites are filled with quartz, which is at times in solid irregular areas; at other times in little grains; sometimes in micropoikilitic intergrowths with an alkali feldspar. There are also irregular masses of this feldspar present, but they are rare.

The whole character of this rock shows that it is of an alkali type and one in which soda predominates; it bears the same relation to ordinary syenite-porphyry that the Litchfieldite type of eleolite-syenite does to ordinary varieties. This character of the rock impresses itself sharply on the large phenocrysts mentioned above. While with low magnifying powers they show an even unstriated appearance, when examined with high ones it is seen that they are composed of a mingling of two kinds of feldspar substances. They then present between crossed nicols on a gray background an excessively fine spotting of a material which has a somewhat higher double refraction, polarizing in higher tones of white. They recall sheets of iron which have been coated with zinc, or the frosting on a window pane, with a

varied, flamed, or clouded aspect. They are probably similar in some respects to the moiré feldspars described by Brögger. The mingling is of too fine a nature and the particles too minute for the two varieties to be separated and distinguished by optical or chemical means. These fine particles, which are believed to be of albite formed by a secondary breaking up of the soda orthoclase or anorthoclase molecule—are in general oriented similarly with the main feldspar, but not always; in the main, however, the section extinguishes similarly over the whole field. Frequently, also, the phenocryst has a fine outer mantle or skin of the same substance. Scattered through the feldspar phenocryst thus composed, are great quantities of slender laths of albite. They peg the large phenocryst through in every direction and present no regularity of orientation with it, or with one another. They are twinned according to both the Carlsbad and albite laws; often the lath is twinned in halves and as the Carlsbad halves have a nearly simultaneous extinction with the albite twins it is difficult in this case to determine which method is present. That the laths are of albite is shown by optical tests mentioned above, where both twinnings are present, and is to be inferred from the chemical test made for lime. In a few cases the phenocrysts contained these inclusions as short, broad sections oriented in zonal planes. It is believed that these included albites are not secondary, but are of the same age as those in the groundmass, and that their presence shows that the phenocrysts containing them are also of the same age. Thus the phenocrysts spreading outward in their growth would include the albite microlites already formed, but which had not yet developed the stout, thick form, which at present characterizes them in the groundmass.

Summary of petrography.—The study which has been made upon these rocks of the Little Rocky Mountains shows them to belong in the alkali granite-syenite series. The magma which formed them has cooled and crystallized under conditions which gave rise to the granite-porphyry rather than the granular type of structure. On the whole it has been very free from lime, iron,

and magnesia, as shown by the infrequency or absence of minerals containing these elements and by the alkaline nature of the feldspars. There has been, however, a certain amount of differentiation or variation in its character and the resultant rocks grade from true granite-porphyries through quartz syenite-porphyries into syenite-porphyry. In one case, through local increase in lime, they pass into a granite-diorite-porphyry. While the alkaline magma in general is high in silica, a local differentiation, has produced a form rich in alkalies but low in silica, as shown by the tinguaite.

The results then show that petrologically the magmas of the Little Rockies conform to the general type of the detached mountain groups of central Montana in that they are of alkaline, highly differentiated character;[1] they appear to differ in one respect from the general characteristic of this petrographical province in that soda dominates the potash, though but slightly. The occurence of tinguaite adds another locality to the few already known American occurrences of phonolitic rocks. Such rocks have been described from the Black Hills of South Dakota,[2] from Arkansas,[3] from the Trans Pecos district, Texas,[4] from Cripple Creek, Colo.,[5] and from the Bearpaw Mountains of Montana,[6] and specimens have also been received from the Sweet Grass Hills of Montana. Closely related types also occur in the Crazy Mountains of Montana.[7]

Ore deposits.—The ore deposits of the Little Rocky Mountains are of considerable scientific interest, since they represent a type that has thus far been noted at very few localities in this

[1] Highwood Mts. Bull. Geol. Soc. America, Vol. VI, p. 389. 1895. Phonolitic Rocks from Montana, Am. Jour. Sci., Vol. L, 1895. Igneous Rocks of Sweet Grass Hills, Montana, Am. Jour. Sci., Vol. L, 1895.

[2] Pirsson, Am. Jour. Sci., Vol., XLVII, p. 341, 1894.

[3] J. F. Williams, Ig. Rocks Arkansas, pp. 99, 146, 264, 277, 351, 367. 1890.

[4] Osann, Geol. Surv. Texas, Ann. Rep., 1892, p. 130.

[5] Cross, Proc. Colorado Sci. Soc. 1887, p. 167. Pikes Peak Folio, Geol. Atlas, U. S. Geol. Surv. 1894.

[6] Am. Jour. Sci., Vol. L, p. 394.

[7] Wolff and Tarr, Bull. Mus. Comp. Zool., Cambridge, Vol, XVI, 1893, p. 230.

country—a type that is well known because it prevails at the famous Cripple Creek district of Colorado. While the deposits are as yet but little developed, they promise to be actively exploited when the mineral lands which are now within the limits of the Fort Belknap Indian reservation shall be declared open to location. The gold ores are tellurides associated with fluorite, and occur in the altered porphyry. This character of ore, and its association with phonolitic rocks, is of such interest, that it seems appropriate to record here the association of telluride ores with phonolitic rocks which observation shows to prevail not only at the Cripple Creek region but in the Black Hills of Dakota and in the Judith Mountains of Montana.

The mineralized zone, which extends to the vicinity of Indian Peak in a northeast direction across to the north slope of Granite Mountain, is probably about 2000 feet or more in width. Within this area the rock is generally bleached and rotted, white, rusty or pink in color, and cut by veins in which the rock is seamed by quartz stringers and quartz films, and with cavities filled with rusty ore. The pitch of the ore body is steep, some 80° perhaps, and the rock is generally broken by fracture into some angular bits or blocks a foot or so long.

The ores carry gold and occasionally silver. They consist of brecciated or shattered country rock impregnated, coated, and replaced by quartz, often associated with fluorite and carrying small amounts of telluride, pyrite, and possibly other minerals. The ores do not occur in well defined fissure veins with definite mineral walls. The gold occurs both as a telluride and as free gold. In the altered ore forming the surface of the ore deposits and the "float" of the mineral belt, the gold can be seen to be free, but in many cases the gold can only be seen after roasting the ore. A characteristic ore of the district consists of an intimate mixture of quartz and fluorite, whose brilliant purple color makes it readily recognizable.

Superficial alteration of the deposits has caused the oxidation, hydration and leaching of the ore, which consists of a granular, friable, vesicular quartz more or less incoherent and

stained a rusty color by iron. In most of the ore free gold is seen in small spongy masses of a dark coppery color.

The slight amount of development work as yet carried on makes any conjecture as to the mode of occurrence of the ore bodies quite hypothetical. The total absence of dikes, and the fact that no contact deposits have been found, points to the origin of the deposits as due to the alteration of shattered zones of the porphyry itself. That there has been some movement and fracturing of the porphyry since its consolidation is proven by the slickensided surfaces seen near the Alabama mine. The presence of fluorite may have some connection with the telluride ores which are the source of the gold. In the mines of the Judith Mountains the richest ores occur associated with fluorite, and the source of the free gold seems to have been the telluride minerals. This association of fluorite with gold has been noted by various observers at Cripple Creek and in Boulder county, Colorado.[1]

The *Goldbug* mine is the only property which shows any considerable amount of development. It is owned by G. L. Manning and the heirs of Pike Landusky. It was bonded some years ago to the owners of the famous Granite Mountain mine, but was relinquished and is now bonded by another syndicate, who are having the ore body prospected, under the superintendence of M. H. Jacobs, formerly of Hailey, Idaho, whose many courtesies are here gratefully acknowledged. The Goldbug claims are located upon the breccia and shattered porphyry, whose crushed condition permitted the ready passage of mineralizing waters acting upon the feldspathic and basic constituents of the rock, replacing them and filling the seams with quartzose material which is gold bearing.

WALTER HARVEY WEED.
LOUIS V. PIRSSON.

WASHINGTON AND NEW HAVEN,
April 1896.

[1] Mining Geology of the Cripple Creek District, Colorado, by R. A. F. PENROSE, JR., 16th Annual Report of the Director of the U. S. G. S., Vol II, Washington, 1896.